An Analysis of Processing and Properties of the Ultra-high Strength Steel Sheets

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Abstract. Investigation of optimal production parameters for ultra-high strength steel sheets is presented. Maraging steel 18Ni9Co5MoTi is applied in experiments. The steel is produced by steelmaking procedure consisted of vacuum induction melting (VI) followed by electric slag remelting (ESR). Obtained ingots were pre formed in square bars by forging. Formed bars were hot rolled in pilot plant in sheet with different deformation degrees and passes depending on the final thickness. Final thicknesses of the sheets were from 2 mm to 6.75 mm. Mechanical properties and microstructure of the pre forms and final products after different thermal treatments conditions were tested. The obtained results are shown that production of ultra-high strength steel thin sheet with tensile strength over 2000 MPa and with acceptable level of plasticity is possible, if the proposed procedure from this work is applied.

Introduction

The Ni-Co-Mo family of steel has been designed with idea to develop high proof stress with optimum toughness for various strength levels. In contrast to conventional ultra- high strength alloy steels in which carbon martensite is necessary for the development of high strength, 18 Ni maraging steel have a very low carbon content and their high strength are derived by age hardening of relatively soft low carbon martensite as well as the toughness of maraging steels is distinctly superior to that of conventional steel at the same strength levels.

Heat treatment of maraging steels is relative simple and special furnace atmospheres to prevent decarburization during heat treatment are not required because of low carbon content. Maraging steels normally are solution annealed (quenched) at 820^{o}C. The cooling rate after annealing has no significant effect on microstructure or properties. Aging normally is done at 480^{o}C for 180 to 480 minutes. The standard aging treatments produce contraction in length of 0.04% to 0.08%. These very small dimensional changes during aging allow many maraging steel components to be final machined in the annealed condition, and then age hardened. Maraging steels are readily weldable without preheat in either the solution annealed or fully aged conditions. All conventional welding processes have been used for welding maraging steel [1, 2].

Maraging steels have been used in a variety of applications as: cannon recoil springs, Belleville springs, bearings, transmission shafts, couplings, hydraulic hoses, bolts and dies. Maraging steels have been extensively used in two general types of application:

- Aircraft and aerospace applications such as: undercarriage parts, wing fittings, solid and liquid propellant missile cases or stored, major part of some combustion chamber, jet engine starter impellers, torque transmission shafts, in which the superior mechanical properties and weldability of maraging steels are the most important characteristics
- Tooling application as: punches and die bolsters for cold forging, cold reduction mandrels in tube production, extrusion press rams and mandrels, some machine components where the

excellent mechanical properties and superior fabrication are important in many applications [2, 3].

In the present work, the aimed has been made to assess the effect of processing parameters on properties of 18Ni maraging steel sheets. Beside that maraging steels were developed and produced over the twenty years ago, this type of steel is still of interest for investigations [3-5].

Experimental

The chemical composition of the maraginig steel tested in this work are given in table 1.

Table 1 The chemical composition of experimental charges [in mass. %]

		Ni	Co	Mo	Ti	Al	C	Si	Mn	S	P	Cr	N	Fe
Charge	Presumed	18.0-19.0	8.5-9.5	4.6-5.2	0.5-0.8	0.5-0.15	max. 0.01	max. 0.05	max. 0.05	max. 0.01	max. 0.01	max. 0.3	0.001-0.015	rest
1	VI	18.4	9.0	5.4	0.50	0.07	<0.01	0.14	0.26	0.015	0.009	0.06	0.0032	rest
	ESR	18.2	8.6	5.4	0.45	0.05	<0.01	0.10	0.08	0.003	0.007	0.02	0.0030	rest
2	VI	18.2	8.9	4.9	0.70	0.20	<0.01	0.08	0.15	0.019	0.015	0.02	0.0044	rest
	ESR	17.9	8.5	4.5	0.60	0.15	<0.01	0.04	0.06	0.003	0.008	0.01	0.0042	rest
3	VI	18.0	8.6	4.8	0.90	0.27	<0.01	0.06	0.17	0.015	0.010	0.03	0.0032	rest
	ESR	17.9	8.4	4.5	0.75	0.18	<0.01	0.05	0.07	0.002	0.006	0.02	0.0028	rest

Comment: 1) Content of the Si=0.02-0.06%, Mn=0.02-0.05%, Cu=0.03-0.05%, Cr=0.06-0.2% is below of the maximal proposed
2) VI - vacuum induction melting, ESR - electro slab remelting

The results In the table is presented required composition and results of the steel composition in the vacuum induction melted charges (VI) and composition of the steel electrode after electroslag remelting (ERS). The content of elements is generally within the required values, except the nitrogen content which is in the range from 0.0028 % to 0.0044 % and it is over the required.

Maraging steel with 18% Ni for investigations is produced by following steelmaking procedures:

- melting in the vacuum induction furnace (VI) and followed with
- electroslag remelting (ESR) in the argon protective atmosphere.

Three charges were produced. The weight of each charge was about 50 kg. Diameter of the ingot after electroslag remelting was ϕ 160 mm. Obtained ERS ingots are pre formed by forging in square bars of the following dimensions: 70 x 70 x 800 mm. The basic technological parameters and deformation during forging of the experimental charges are given in tables 2 and 3.

Table 2. Basic forging parameters of the pre forms for hot rolling

Forging unit	200 t press
ESR ingot dimensions	ϕ 160 x 500 mm
Forging temperature	900-1150^{o}C
Dimensions of forged parts	square70 x 70 x 800 mm
Cooling after forging	Oil
Total deformation degree	75%

The additional deformation is achieved by hot rolling. Square bars were hot rolled to the sheets of the following thickness: 6.75 mm, 4.00 mm, 2.85 mm and 2.00 mm. Plastic deformation by hot rolling of the forged pre forms is performed in the pilot plant with rollers of 350 mm diameter. Hot rolling parameters are presented in the Table 2. Corrosion products from the sheets after hot rolling is removed by the solution consisted of HCl, HF, H_2O_2 and H_2O mixture.

Table 3. Parameters for the hot rolling technology of the sheets

Dimensions forged pre forms	square 70 x 70 x 800 mm
Sheet dimension	6.75 x 70 x 400 mm
	4.00 x 70 x 400 mm
	2.85 x 70 x L mm
	2.00x70x L mm
Temperature range for hot rolling	1200-950°C for 6.75 mm
	1200-900 °C for 4.00 mm
	1200-870 °C for 2.85 mm
	1200-830 °C for 2.00 mm
Cooling after rolling	Air
Total degree of deformation	90 % for 6.75mm
	94 % for 4.00mm
	96 % for 2.85mm
	97 % for 2.00mm
Final degree of deformation	~ 60 %

Mechanical properties of the samples from the pre forms - forged bars and of the final products - sheets were tested. Properties testing of the bars were performed after forging, quenching and ageing. Also properties testing of the sheets were performed on the samples in the hot rolled condition, after quenching and ageing. Quenching and age hardening are preformed in accordance with classical procedure for the maraging steels:

- Quenching at 820°C/20 min /air cooling,
- Ageing at 480°C/180 min / air cooling.

Tensile properties testing are performed in accordance with standards JUS C.A4.002. Absorbed energy was tested on Charpy V samples and hardness is measured by Rockwell C.

The macrostructure and evaluation of the non metallic inclusion content were performed on the forged square bars in accordance with standards SNO 1710 and ASTM 45. Microstructure is analysed on forged, hot rolled, quenched and aged samples on optical microscope after classical grinding and polishing and etching in 15 % Nital solution.

Results And Discussion

The results of the chemical composition of the investigated steel are presented in Table 3.

Quality control after forging by visual inspection and ultrasound has shown that any mistakes are not indicated. Performed investigation of the macrostructure and non metallic inclusions content has shown that all experimental charges had sound macrostructure and low content of the non metallic inclusions.

Table 4. Results of the macrostructure investigation on the forged bars

Charge	Grade A	Grade B	Grade C	Grade D
Presumed	A1	B1	C1	D1
1	A1	-	C1	-
2	A1	B1	-	-
3	A1	B1	-	-

Applied melting and refining procedure involving vacuum induction melting and electro slag remelting held composition within the prescribed limits with close control over impurities. Solidification in water cooled copper mould enabled steel structure with minimal micro and macro segregations. The high standard of cleanness is also obtained [6, 7].

Table 5. Evaluation of nonmetallic inclusion on the forged bars

Charge	A sulphides	B aluminates	C silicates	D oxides	Σ total
1	0.10	0.25	0.20	0.20	0.75
2	0.20	0.30	0.25	0.15	0.90
3	0.10	0.45	0.25	0.10	0.90
mean	0.13	0.33	0.23	0.15	

The results of the mechanical properties tested on samples from bars after forging, quenching and ageing are presented in the Table 6.

Table 6. Mechanical properties of the bars as forged, quenched and aged

Charge	Condition	Rp [MPa]	Rm [MPa]	A_5 [%]	Z [%]	KV300/2 [J]	Hardness [HRC]
1	forged	732	1023	13.5	70.5	114.5	32.0
2		780	1061	13.0	70.5	126.5	31.0
3		747	1045	13.5	72.0	142.5	32.5
1	quenched	695	1027	14.5	72.5	122.5	31.0
2		726	1009	14.5	75.0	144.0	32.0
3		703	1030	14.5	73.5	159.0	31.5
1	aged	1846	1925	6.5	38.0	22.5	52.5
2		1850	1930	9.0	51.5	23.0	52.0
3		1900	1980	8.5	51.5	26.5	52.5
	Presumed	>1850	>1930	>6	>30	15-20	50-54

Comment: quenched at 820^{o}C/20 min /air cooling, aged at 480^{o}C/180 min / air cooling

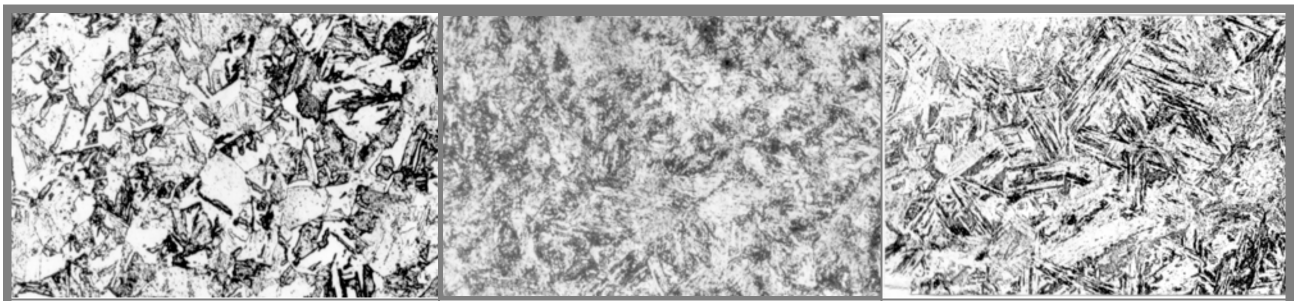
Results show some differences in mechanical properties between forged and quenched samples. Quenched samples had some lower tensile strength and little bit higher plasticity properties as elongation and contraction and higher absorbed energy. Reason for that difference could be incomplete martensite transformation in forged condition and complete transformation in "soft" martensite without retained austenite in quenched condition. Mechanical properties results of forged and aged samples are in accordance with presumed values for maraging steels. The results of the hot rolled and quenched samples (thickness of 2 mm), are presented in Table 7. There is slight difference between the properties of the hot rolled and hot rolled and quenched samples. Tensile strength of hot rolled and aged sheets is over 2000 MPa, but elongation and contraction are lower in comparison with presumed for forged condition, as presented in Table 7 for different sheet thickness. This decreasing of plasticity could be expected. It is evident some disagreement between degree of deformation and tensile strength. The tensile strength increasing with increasing of the degree of deformation is not obtained. This data have to be further clarified in the future investigations.

Table 7. Mechanical properties of the tested maraging steel sheets

Thickness, mm	Condition	Rm [MPa]	A_5 [%]	Z [%]
2.00	hot rolled	1022	8.8	55.1
2.00	quenched	1017	12.0	49.7
2.00	aged	2166	3.7	14.9
2.85	aged	2177	4.6	10.42
4.00	aged	2032	2.45	7.5
6.75	aged	2046	2.8	7.1

Comment: quenched at 820^{o}C/20 min /air cooling, aged at 480^{o}C/180 min / air cooling

The microstructure of the test steel sheets of 2.00 mm, after different thermal treatments as: hot rolled, quenched at $820^{o}C$/20 min /air cooling and aged at $480^{o}C$/180 min / air cooling, are presented in Figure 1.



a) hot rolled, magn. 100 times, 15 % Nital etched	a) quenched, magn. 100 times, 15 % Nital etched	a) aged, magn. 100 times, 15 % Nital etched

Fig. 1. Microstructure of the tested maraging steel sheets

Microstructure could be defined as Ni-martensite in different types. In forged samples, Fig. 1a) could be expected retained austenite, while in quenched samples (Fig. 1 b) matensite transformation is complete. In aged structure are visible needle like martensite, probably as result of ageing effects. These microstructures are in accordance with obtained tensile testing data.

Conclusion

- The pilot plant production procedure for hot worked sheets of 18Ni9Co5MoTi maraging steel is investigated and summarized. The steelmaking procedure for tested steel consisted of melting in the vacuum induction furnace (VI) and followed with electroslag remelting (ESR) in the argon protective atmosphere. The obtained steel is characterised with high cleanliness and it is suitable for further plastic deformation.
- Hot working procedure, consisted of ingots forging to bars pre forms and their hot rolling with corresponding heat treatment. Final dimensions of hot rolled maraging steel sheets were 2.00, 2.85, 4.00 and 6.75mm.
- The suggested procedure confirmed that production of ultra - high strength maraging steel sheets, with tensile strength over 2000 MPa and with acceptable level of plasticity, could be obtained.

References

[1] R.W.K. Honeycombe: "Steels-Microstructure and Properties", Edward Arnold, London, (1981), pp. 165.

[2] R.F. Decker: "Source book on maraging steels", AMS, Ohio, (1979), pp. 351.

[3] C. R. Shamantha at al: Materials Sci. and Eng. A, Vol. 287, Issue 1, 15 July (2000), pp. 43-51.

[4] R. Kapoor at al: Materials Sci. and Eng. A, Vol. 287, Issue 1-2, 15 July (2003), pp. 318-324.

[5] T. Christopher at al.: Fat. Frac. Eng. Mat. Struct, Vol 27, Issue 3, March (2004), pp. 177.

[6] Z. Odanović: "Prilog osvajanju martenzitno starenih čelika", VTI Beograd, (1988), pp. 26.

[7] M. Rimac at al: "Osvajanje tehnologije izrade martenzitno starenog čelika 02N18K9M5T", IHB Zenica, (1988), pp. 14.